SOUNDINGS AND DREDGINGS OBTAINED ON PASSAGE FROM DISCO TO ENGLAND.

In Davis Strait.

No. of Station.	Lat. N.	Long. W.	Depth in fms.	Nature of bottom.	Bottom-temp.	Remarks.
1.	70° 30′	54° 41′	175	Sand, mud.	.....	Dredging.
2.	70 27	55 0	85	Gravel, stones.	.....	Ditto.
3.	69 31	56 1	100	Mud.	.....	Ditto.
4.	67 56	55 27	20	Broken barnacles and shells.	.....	Ditto.
5.	66 55	55 30	57	Rock, sand, shells.	.....	Ditto.
6.	64 5	56 47	410	Sand, mud.	34°6	Serial temperature, dredging.
7.	63 9	56 43	1100	Clay, mud.	36·4	Ditto ditto.
8.	62 6	55 56	1350	Mud (blue clay under).	34·6	
9.	59 10	50 25	1750	Ditto.	34·0	Dredging.
				In North Atlantic.		
10.	58 14	46 29	1660	Fine sand.	34·3	Serial temperature.
11.	57 50	44 52	1860	Globigerina ooze.	33·4	
12.	56 11	37 41	1450	Glob.-ooze, stone.	36·3	Serial temperature, dredging.
13.	56 1	34 42	690	Glob.-ooze.	38·2	Dredging.
14.	55 58	31 41	1230	Mud.	36·8	
15.	55 58	28 42	1485	Clay, blue mud.	36·5	Serial temperature.
16.	55 10	25 58	1785	Glob.-ooze (blue mud under).	36·7	Dredging.

N.B. In the accompanying Chart (Plate 2) the outward course of the voyage is shown by a plain line, and the homeward or return course by a dotted line.

XXV. "Report on the Physical Investigations carried on by P. Herbert Carpenter, B.A., in H.M.S. 'Valorous' during her Return Voyage from Disco Island in August 1875." By William B. Carpenter, C.B., M.D., F.R.S. Received June 15, 1876.

Introduction.

The despatch of H.M.S. 'Valorous' to Disco Island, in the summer of 1875, with stores for the use of the Arctic Discovery Ships, having afforded an opportunity for the prosecution of a Deep-Sea Physical and Biological Exploration of the North Atlantic and Baffin's Bay, which should be complementary to the work elsewhere carried on by the 'Challenger,' a suggestion for the prosecution of this inquiry on the return voyage of the 'Valorous' was made by the Council of the Royal

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Society, and approved by the Admiralty. Dr. Gwyn Jeffreys having undertaken the general charge of the work, named as his assistant my Son, Mr. P. Herbert Carpenter, who had accompanied me in the 'Lightning' and 'Porcupine' Expeditions; and it was arranged that, while aiding Dr. Jeffreys in the Biological work, he should take special charge of the Physical.

A grant from the Donation Fund having been made to Dr. Jeffreys and myself for the expenses of the inquiry, I endeavoured to make such provision for the conduct of the Physical observations as should render them capable of accurate correlation with those of the 'Challenger.' With this view, I obtained two water-bottles, on the construction devised by Mr. Buchanan (the Physicist of the 'Challenger'), from Messrs. Milne, of Edinburgh, by whom they had been supplied to him; and also two Hydrometers, on Mr. Buchanan's construction, from Messrs. Kemp, who had previously made them under Mr. B.'s direction.

Unfortunately, however, my Son was unable to utilize the water-bottles thus provided: for as Captain Nares had not been supplied with any water-bottle, it was deemed right to comply with his pressing request that one of these bottles should be transferred to him; and the other bottle failed in its work, in consequence of some defect in its construction which the armourer of the 'Valorous' was unable to remedy*. No Specific-Gravity observations could be made, therefore, on any but surface-water; these, however, were very systematically carried out; and Mr. Buchanan has kindly undertaken to compare our Hydrometers with his own, and to furnish the formula for the exact correction of the 'Valorous' observations, so that results may be worked out which shall be strictly comparable with those obtained in the 'Challenger' Expedition.

Having been supplied by my Son with the entire series of Deep-Sea Temperature-observations, the results of which have been embodied in Sections prepared at the Hydrographic Office of the Admiralty, I now present a Report upon these, in which I have drawn attention to what seem to me their chief features of interest.

Report.

In the first of the Serial Soundings taken by the 'Valorous' (see Plate 2. Station 6, and Plate 3. No. VI.), nearly in the middle of Davis Strait and on the parallel of Godthaab, the bottom-temperature, at a depth of 410 fathoms, was 34°·6 Fahr.; and the descent to this from a surface-temperature of 40° was nearly uniform—39°, 38°, 37°, 36°, and 35° being met with at almost equal intervals. There was here, therefore, no indication of any contrary movement of different strata of water, or of any special superheating of the superficial stratum. But the

* Mr. Buchanan tells me that the like defect existed in all the water-bottles supplied to the 'Challenger' by Messrs. Milne, the construction of which he had not personally superintended.

case was very different with the next much deeper sounding (Plate 2. Station 7), which was taken about a degree further south, but still towards the middle of Davis Strait: for there was here (Plate 3. No. VII.) a surface-stratum of 45°, but of such extremely small thickness, that the isotherm of 40° was reached in about 15 fathoms; from 40° to 38° the interval was nearly the same as in the previous sounding; but below 38° the descent was so slow that 37° was not reached until nearly 800 fathoms, and on the bottom at 1100 fathoms the temperature was still 36°·4. At the next station (Plate 2. Station 8), Lat. 62° 6′ N., Long. 55° 56′ W. (that is, another degree further south, and at about the same distance from the Greenland coast), a depth of 1350 fathoms was met with; the surface-temperature was still 45°; but the bottom-temperature was found to be 34°·6, as in the 410 fathoms sounding. The next temperature-sounding (Plate 2. Station 9, and Plate 3. No. IX.) was taken nearly 3 degrees further south and 5½ degrees to the west, namely in Lat. 59° 10′ N., Long. 50° 25′ W.; that is, a little to the south of Cape Farewell, but still six degrees to the west of it: here the surface-temperature was still 45°; but the bottom-temperature at 1750 fathoms had sunk to 33°·4. Finally, a set of serial soundings (Plate 2. Station 10, Plate 4. No. X.) was taken before rounding Cape Farewell, about a degree further south and 4 degrees east: the surface-temperature had then risen to 49°; but the isotherm of 40° was reached at about 50 fathoms, that of 39° at about 90 fathoms, and that of 38° at about 160 fathoms; whilst below this the descent of the thermometers was extremely slow down to the isotherm of 37°, which lay at about 1050 fathoms—becoming more rapid, however, beneath this, so that 36° was reached at about 1400 fathoms, 35° at about 1500, and 34°·3 on the bottom at 1660 fathoms.

Now these phenomena seem to me to point very distinctly to the existence (1) of a superheated layer, which is slowly moving up Davis Strait, and gradually losing its excess of temperature as it proceeds north, as shown by the gradual approach of the isotherms to the surface; (2) of a neutral intermediate layer, 1000 fathoms or more in thickness, marked out by the extreme uniformity of its temperature, which indicates its stationary condition; and (3) of a deep cold layer, which as clearly derives its low temperature from a northern source, as the uppermost stratum does from a southern, and which must, therefore, be in movement.

The Temperatures at Station VI. (Plate 3.) seem at first sight rather anomalous when compared with those of Stations VII.–X.—the isotherm of 37° here coming up within 200 fathoms of the surface, whilst at only a degree further south it lies at nearly 800 fathoms; and a bottom-temperature of 34°·6 being found at 410 fathoms at Station VI., whilst at Station VIII. it is only reached at 1350 fathoms. But the anomaly disappears when the rapidly increasing depth and the tendency of the coldest water to gravitate to the bottom are taken into account: for

it appears, from the temperature-soundings taken further north towards Disco Island by the Swedish ship 'Ingegera' (Plate 3. Nos. I.–V.), that water as cold as this, and even much colder (31° being recorded in one instance), is there found at depths varying between 58 and 185 fathoms; and it can scarcely be doubted that the water which is chilled by the more severe cold of Baffin's Bay is here flowing down the slope of Davis Strait. Again, it is at first sight an anomaly to find at Station VIII. a bottom-temperature of 34°·6 at 1350 fathoms, while the bottom-temperatures both to the north and to the south of it are 34°·6; but this only shows that the coldest Polar water is flowing south through some deeper channel, perhaps in the western half of Davis Strait*. And the same explanation applies to the yet more remarkable fact that a bottom-temperature of 33°·4 was met with near the mouth of Davis Strait, when no such water was met with further north. But that even this does not carry down the coldest water of the Arctic basin, is obvious from the fact brought to light by the 'Porcupine' temperature-soundings in the "Lightning Channel" (between the north of Scotland and the Färöe Islands), over a large part of whose bottom we found the temperature to range two degrees, or even more, *below* 32°.

The next temperature-sounding (Plate 2. Station 11, Plate 4. No. XI.), taken on the 17th of August almost exactly in the meridian of Cape Farewell, and not quite two degrees to the south of it, gave, like No. IX., a bottom-temperature of 33°·4 at 1860 fathoms; so that it seemed pretty clear that this is the temperature of the coldest water that can find its way into the North Atlantic along either the west or the east coast of Greenland. And from the depth at which the isotherm 35° was found to lie in the 1660 fathoms serial sounding, it is obvious that the stratum between 35° and 33°·4 must be here a very thin one; whilst the upward slope which is indicated by the next sounding shows that it must rapidly die out towards the east.

The course of the 'Valorous' having then been kept at first nearly due East, and afterwards S.E., another serial temperature-sounding (Plate 2. Station 12, Plate 4. No. XII.) was taken on the 19th of August in Lat. 56° 11′ N., and Long. 37° 41′ W. The surface-temperature had here risen to 53°,—about the same as we had encountered in the "Lightning Channel," at the same time of the year, rather further to the north; but the warm upper stratum was here thinner, a reduction

* As I pointed out on a former occasion (Proc. Roy. Soc. vol. xx. p. 624. § 144), any water moving from either Pole towards the Equator will have a *westerly* tendency in virtue of its *deficiency* of easterly momentum; just as water moving from the Equator towards either pole will have an *easterly* set, in virtue of the *excess* of easterly momentum which it carries with it.—The later temperature-soundings of the 'Challenger' in the South Atlantic have given the explanation of the temperature of 32°·4 observed under the Equator in the first year of her voyage, but not encountered in any of the earlier temperature-soundings taken in the South Atlantic, by showing that the coldest Antarctic underflow is met with on the *westerly* part of its sea-bed.

to 45° taking place within 50 fathoms, and to 40° within 300; whereas in Lat. 59° 35′ N., Long. 9° 11′ W. we had found the isotherm of 45° lying below 500 fathoms, while the bottom at 767 fathoms was still 41°·4. It is obvious moreover, from the regularity of the descent of the isotherm of 40° in this part of the North Atlantic, that *easting* has more influence on the rate of that descent than *southing*—thus confirming the view formerly expressed as to the tendency of the warm upper flow towards the *eastern* side of the basin *. The isotherms of 39° and 38° slope downwards towards the east at about the same rate; but those of 37° and 36° still nearly keep their parallelism to the surface, confirming the previous suggestion of the "neutrality" of the deep stratum which they underlie.

Between the last station and the next (Plate 2. Station 13), taken in Lat. 56° 1′ N. and Long. 34° 42′ W., in the line of the channel between Iceland and Greenland, but considerably to the south of it, the sea-bed was found to have shallowed most remarkably (Plate 4. No. XIII.), bottom being struck at 690 fathoms, and the bottom-temperature rising again to 38°·2. This elevation may be regarded with great probability as a continuation of that which was encountered by Sir L. M'Clintock in the line of temperature-soundings which he took several years ago across the North Atlantic between Rockall and Cape Farewell; for almost exactly in a line between the 'Valorous' Station 13 and Iceland, Sir L. M'Clintock met with bottom at 743 fathoms, between 1260 fathoms on the east and 1159 fathoms on the west.

The course being now again kept nearly due east, another temperature-sounding (Plate 2. Station 14, Plate 4. No. XIV.) was obtained in Lat. 55° 58′ N., Long. 31° 41′ W., which, on a bottom of 1230 fathoms, gave a bottom-temperature of 36°·8, the surface-temperature being 54°·5. Three degrees further east, and on the same parallel (Pl. 2. Station 15), another set of serial temperatures was taken (Plate 4. No. XV.) which indicated a further increase in the upper warm stratum, the isotherm of 40° descending to about 380 fathoms; but the depths of the isotherms of 39°, 38°, and 37° show little change; and the bottom at 1485 fathoms was 36°·5, as at the corresponding depth on the other side of the ridge. Still further to the east (Plate 2. Station 16, Plate 4. No. XVI.), in Lat. 55° 10′ N., Long. 25° 58′ W., the depth was found to have still further increased to 1785 fathoms; but the bottom showed no lower a temperature than 36°·7, although in the 1750 fathoms sounding on the other side of the ridge the thermometer fell to more than *three degrees lower*.

Bad weather having come on, it was not considered prudent, in the disabled condition of the ship, to attempt further scientific explorations; and the course was accordingly shaped for Cork.

The Temperature-Section prepared from the serial soundings taken in the 'Valorous' after quitting Davis Strait has been continued towards Va-

* Shearwater Scientific Researches, 1872, §§ 144, 148 (Proc. Roy. Soc. xx. pp. 624, 626).

lentia (Plate 4. No. XVII.) on the basis of the serial soundings taken off the coast of Ireland in the first cruise of the 'Porcupine' in 1867, a sounding (No. 22) in 1263 fathoms, Lat. 56° 8′ N., Long. 13° 34′ W., being taken as the principal guide. This being almost on the same parallel with the last serial sounding of the 'Valorous' (the difference of latitude being only half a degree), and the seasonal difference being rather in favour of the 'Valorous' temperatures, it is extremely striking to find in this Section the most remarkable contrast yet brought out between the thermal condition of the eastern and the western sides of the North Atlantic: for the descent of all the isotherms as they pass from west to east, which has been already pointed out in the 'Valorous' portion of the section, continues at an even more rapid rate; so that the isotherm of 40°, which lay at Station XVI. at 380 fathoms, lies at 900 fathoms at Station XVII., 15 degrees to the west; whilst the isotherm of 45°, which at the first of these stations lay at 80 fathoms from the surface, lay in the second at 640 fathoms. This difference in the thickness of the whole stratum above the isotherm of 40° is much more remarkable than the difference of surface-temperature, the increase of which between the first and the second station was only from 55° to 59°·6.

It is clear, therefore, that the heating power of the warm flow which comes up from the S.W. towards the western shores of the British Isles, and which proceeds onwards to the N.E., so as to ameliorate the climate of the Orkneys and Shetland Islands, but still more markedly to affect that of the coast of Norway (as has been shown by Prof. Mohn), depends upon *its great depth*. Any such superheated film as the Gulf-stream has been found to be when last recognizable as a current (as was long since urged by Mr. Findlay, and has since been confirmed by Capt. Chimmo's observations) must lose its excess of warmth long before it reaches our shores. Hence, as I have urged on a former occasion (Proc. Roy. Soc. vol. xx. pp. 621, 637. §§ 137, 163), the prolonged heating power of the N.E. flow depends much more upon the thickness of its moderately warm stratum than upon its bringing with it a high surface-temperature. A layer of 50 fathoms at 60°, flowing N.E. over a bed of ocean-water at 40°, and exposed above to an atmosphere of 40°, would be cooled down to that standard in two or three weeks. But a layer of 900 fathoms thickness, ranging from 40° to 55°, would retain an excess of temperature far longer.

The advocates of the doctrine that the *vis a tergo* is the Gulf-stream, which cannot be traced as a current by any distinctive feature further to the N.E. than the parallel of 40° and the meridian of 30°, have to show in what way it can raise the temperature of so thick a stratum of ocean-water as we have seen to be affected in the Western portion of the North Atlantic by a warm flow of some kind. Whether, as Prof. Wyville Thomson maintains, the approximation of its boundaries between the British Islands on one side and Labrador and Greenland on the other

can possibly produce this result, is a point on which it is for Hydrographers to decide. For myself, I cannot regard it as probable that a spent stream of 50 fathoms thickness can give motion to a vast layer of 900 fathoms depth.

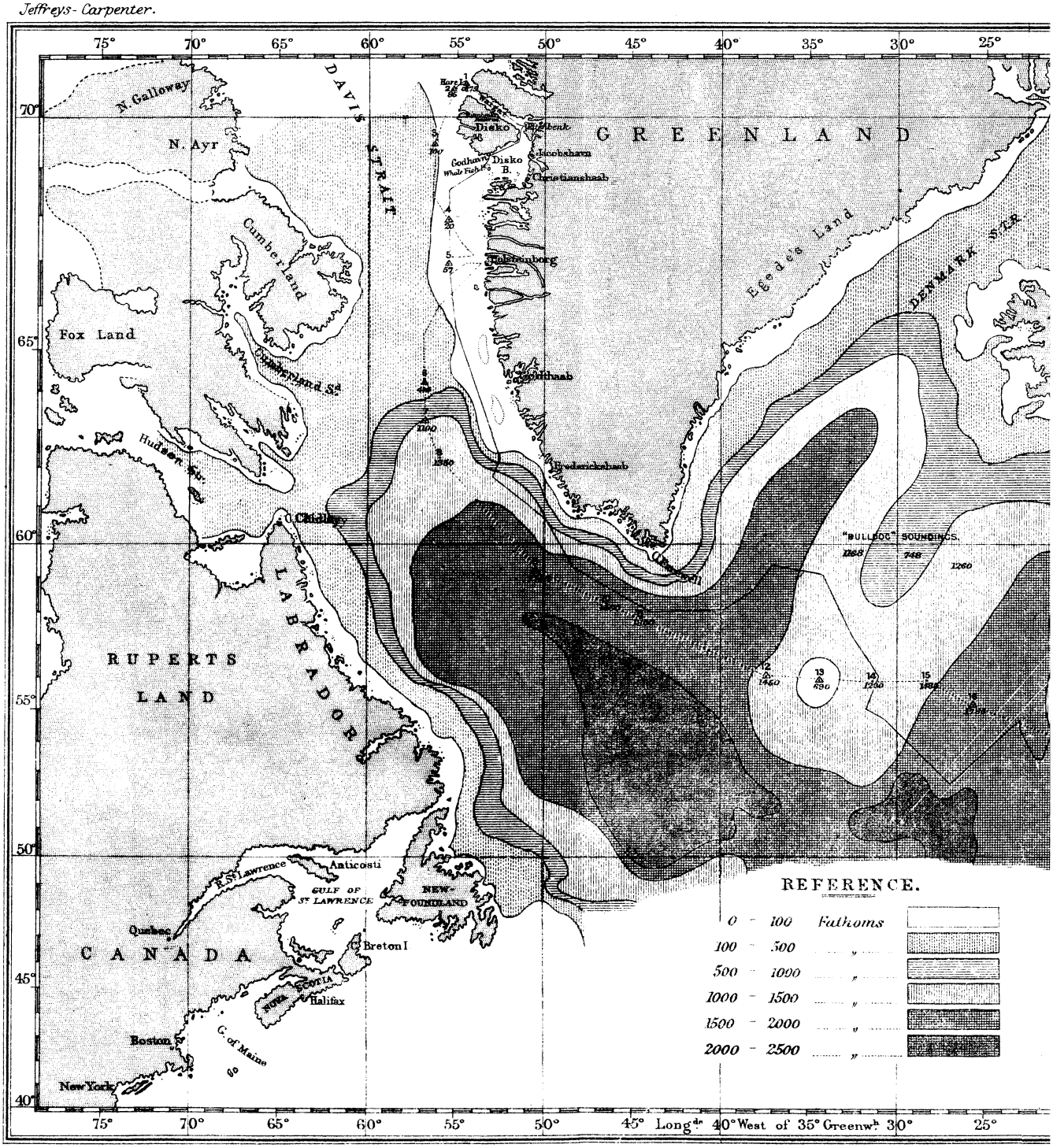
On the other hand, the doctrine I advocate that a thick upper stratum of the North Atlantic is slowly moving Polewards, to fill up the void left by the gravitation-underflow of the coldest water towards the equator, and that this stratum will also have an Easterly tendency in virtue of the excess of easterly momentum which it brings with it from a lower latitude, seems adequately to account for the facts now brought to light. The progressive closing in of the boundaries of this poleward upper flow will obviously tend to deepen it, so as to give it a more persistent heating power*. In the South Atlantic and Southern Indian Oceans, on the other hand, the progressive opening-out of the ocean-boundaries, as we pass Southwards from the Equator, will tend in the same measure to reduce the thickness of the Poleward upper flow, thus diminishing the persistence of its heating power. And in this, as it seems to me, we have the true explanation of the marked difference between the climate of Kerguelen's Land (Lat. 50° S.), for example, or that of Heard Island (Lat. 53° S.), and that of Ireland (lying between the parallels of $51\frac{1}{2}°$ and $54\frac{1}{2}°$ N. Lat.), the summer temperature of the former being but little above the winter temperature of the latter.

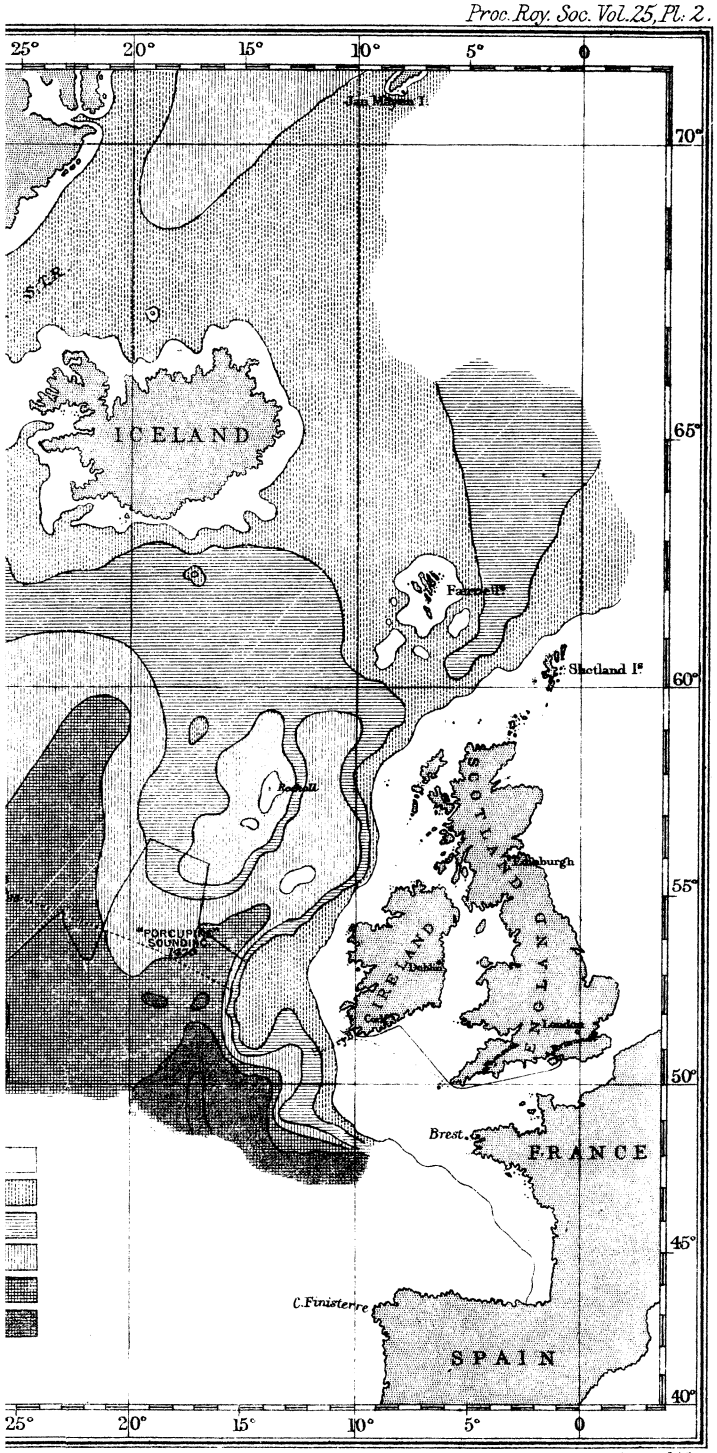
The 'Challenger' temperature-sections have most conclusively shown that the entire warm upper stratum in the South Atlantic is very much thinner than that of the North Atlantic; and while I fully admit that a part of this difference is due to the fact that a far larger portion of the Equatorial current is deflected into the latter than into the former, I cannot see that the Gulf-stream by any means accounts for the descent of the isotherm of 40° in Lat. 56° N. to a depth of 900 fathoms.

The 'Valorous' temperature-soundings seem to me to be of peculiar interest and value, in furnishing a satisfactory explanation of the comparatively high bottom-temperature of the North Atlantic. I have always attributed this to the comparative narrowness of the channels of communication between the Arctic and the North-Atlantic basins, which restrict the flow of the coldest Polar water from the former into the latter; and long before the 'Challenger' Expedition sailed, I had ventured the prediction that the South Atlantic, on account of the perfect

* This position may seem inconsistent with the objection just taken to the doctrine of Sir Wyville Thomson. But the inconsistency is only apparent. I cannot conceive that after the Florida Current has spread itself out like a fan over the Mid-Atlantic, it can retain enough *vis a tergo* to give a N.E. movement to a mass of water nearly 2000 miles wide and 700 or 800 fathoms deep, the impelling force being progressively weakened by the obstacles to that movement. On the other hand, the force which (on the doctrine of a Thermal circulation) acts as a *vis a fronte*, grows stronger as the water which it puts in motion approaches the Polar area, and thus is fully competent to deepen the poleward stratum in proportion to the reduction of its breadth.

Jeffreys- Carpenter.





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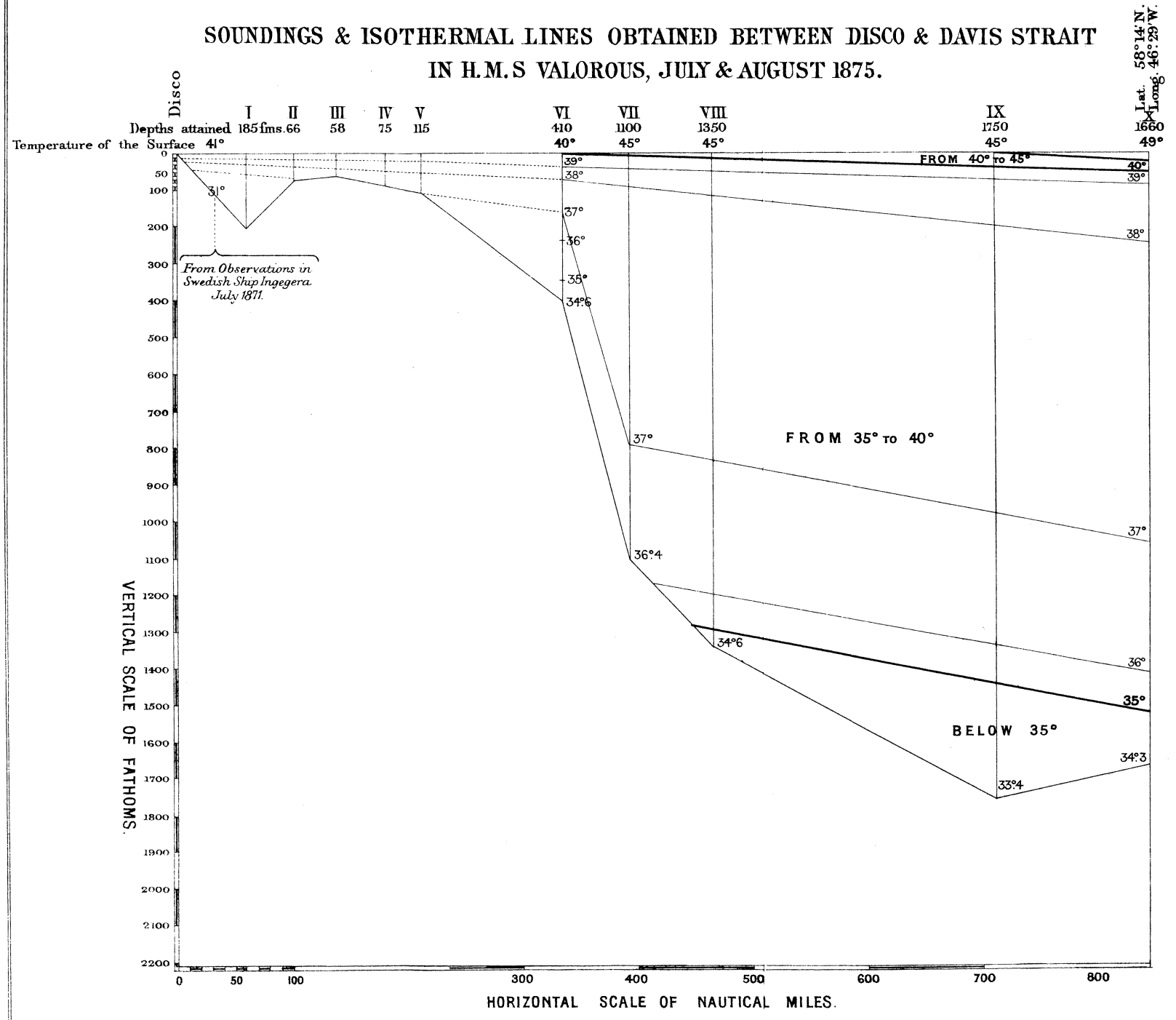
SOUNDINGS & ISOTHERMAL LINES OBTAINED BETWEEN DISCO & DAVIS STRAIT IN H.M.S VALOROUS, JULY & AUGUST 1875.



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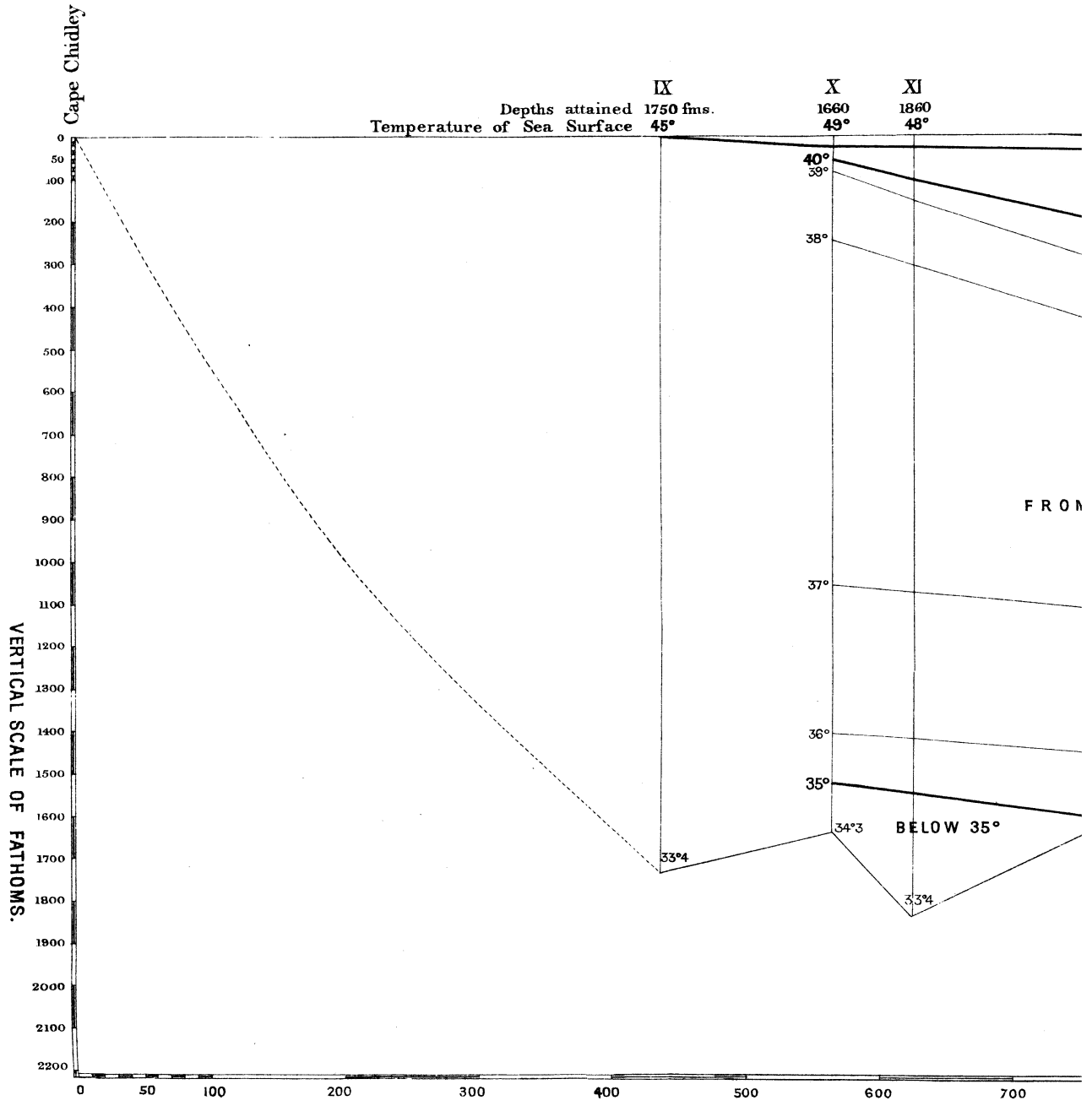
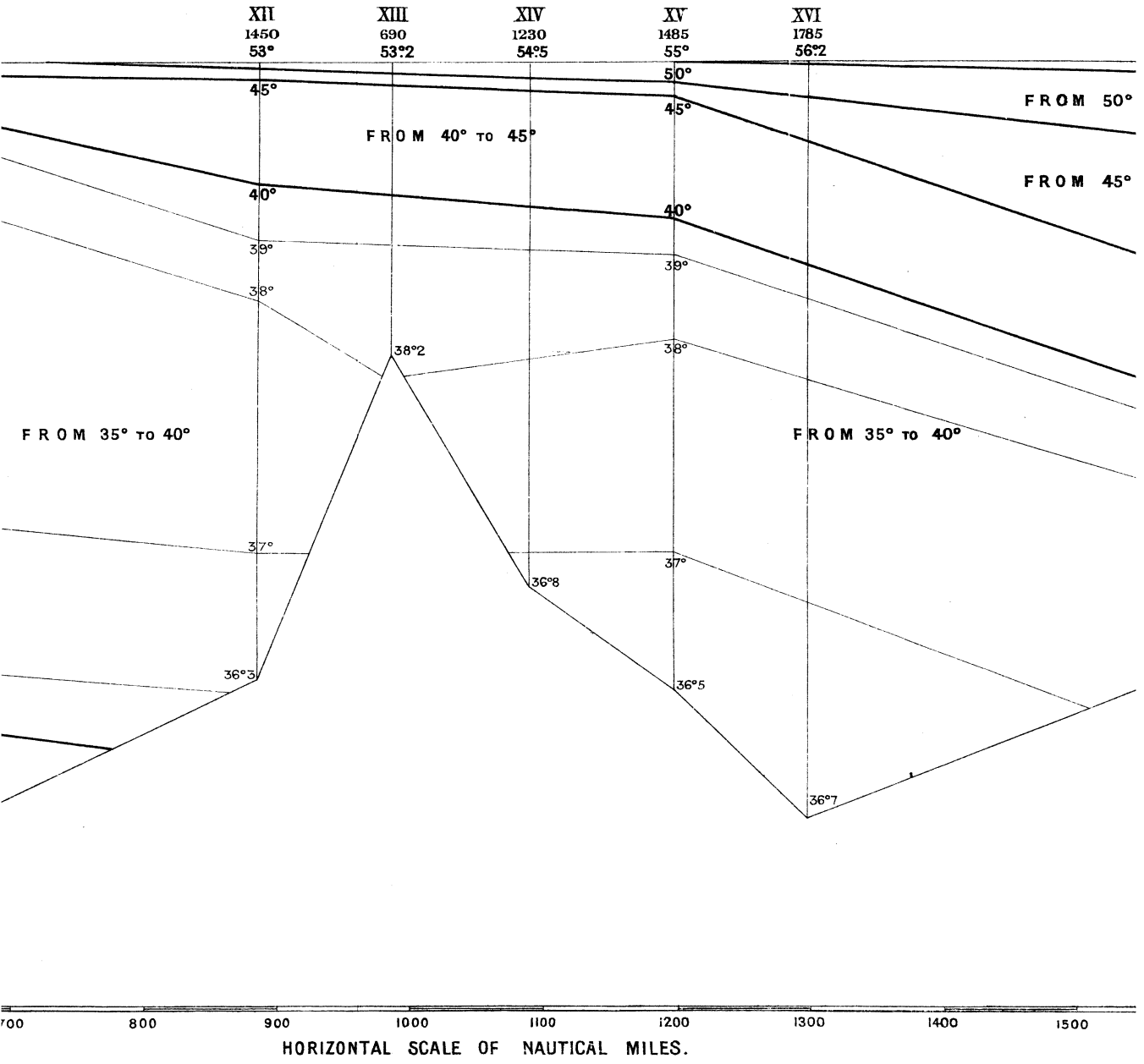


OTHERMAL LINES OBTAINED BETWEEN DAVIS STRAIT & ENGLAND IN H.M.S. VALOROUS, AUGUST 1875.



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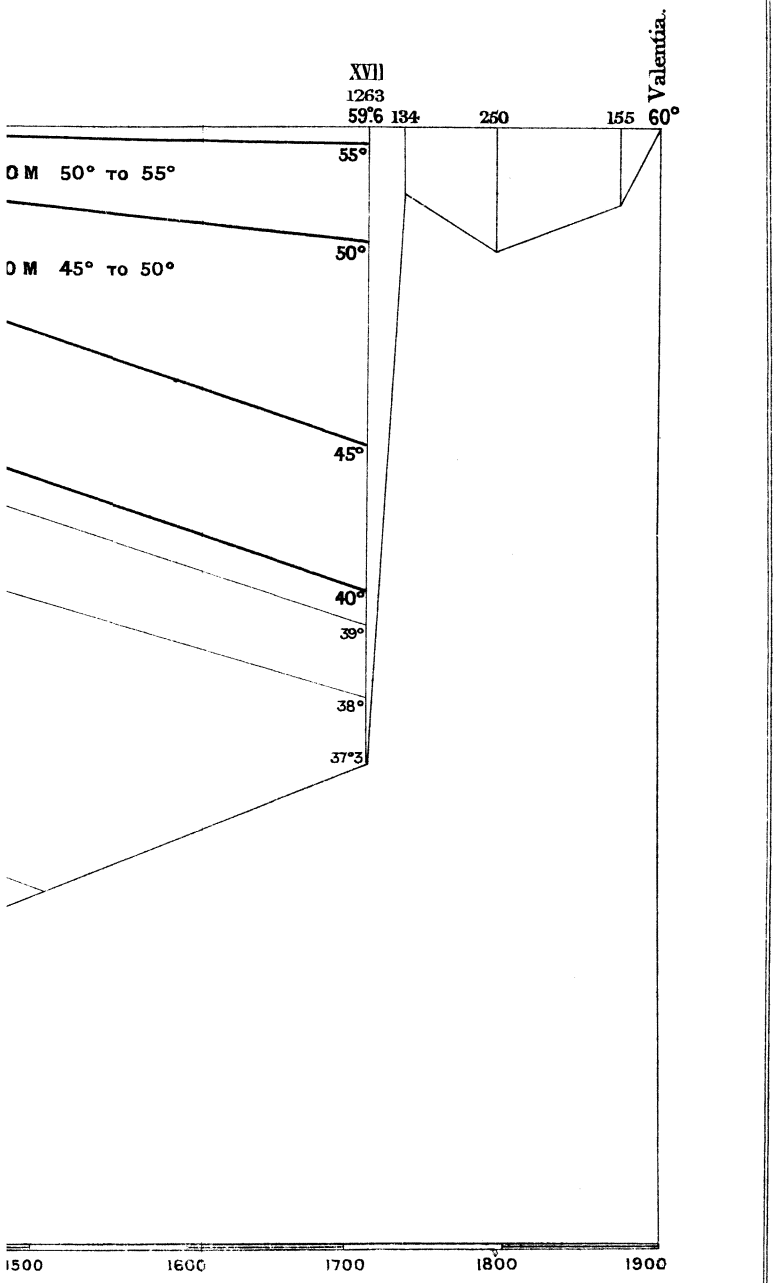
HORIZONTAL SCALE OF NAUTICAL MILES.



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freedom of its communication with the Antarctic, would have a colder bottom, and that the influence of the Antarctic underflow would probably extend to the north of the Equator. By Sir Wyville Thomson, on the other hand, it was argued from the commencement that the whole cooling of the deep stratum of the *North* Atlantic is due to the *Antarctic* underflow; and this conviction he repeats in his last utterance on the subject, on the ground of the continuity of the isotherms from the South into the North Atlantic*. The question arises, however, why the deep stratum of the North Pacific, which is undoubtedly fed from the Antarctic, should be so decidedly colder, as the 'Challenger' and 'Tuscarora' soundings show it to be, than the deep stratum of the North Atlantic; and this question appears to me to find an entirely satisfactory answer in the indication furnished by the Second Section (Plate 4), that the Arctic Basin is for the most part separated from that of the North Atlantic by an intervening ridge, which (like many similar ridges discovered by the 'Challenger') allows water of about 36°, but *not colder water*, to pass from the former into the latter. The limited contributions of colder water furnished by Baffin's Bay and the "Lightning Channel" would help to reduce the deep temperature of the North Atlantic generally to the 35°–36° shown in the 'Challenger' Sections; but it is only when, on approaching the Equator, a bottom-temperature below this first shows itself, that I can recognize the influence of the Antarctic underflow.

I forbear, however, to discuss this subject more fully at present, the Admiralty not having yet published the final instalment of the 'Challenger' temperature-sections. And I shall confine myself to an expression of my earnest hope that the ship to be sent next year to communicate with the Arctic Expedition may have, as part of its work, the completion of that which the 'Valorous' was disabled from performing—namely, the obtaining a continuous temperature-section between Iceland and Greenland, and another across Davis Strait.

DESCRIPTION OF THE PLATES.

PLATE 2.

Chart showing the track of the 'Valorous' outward and homeward. The latter is the dotted line. The tints represent different depths.

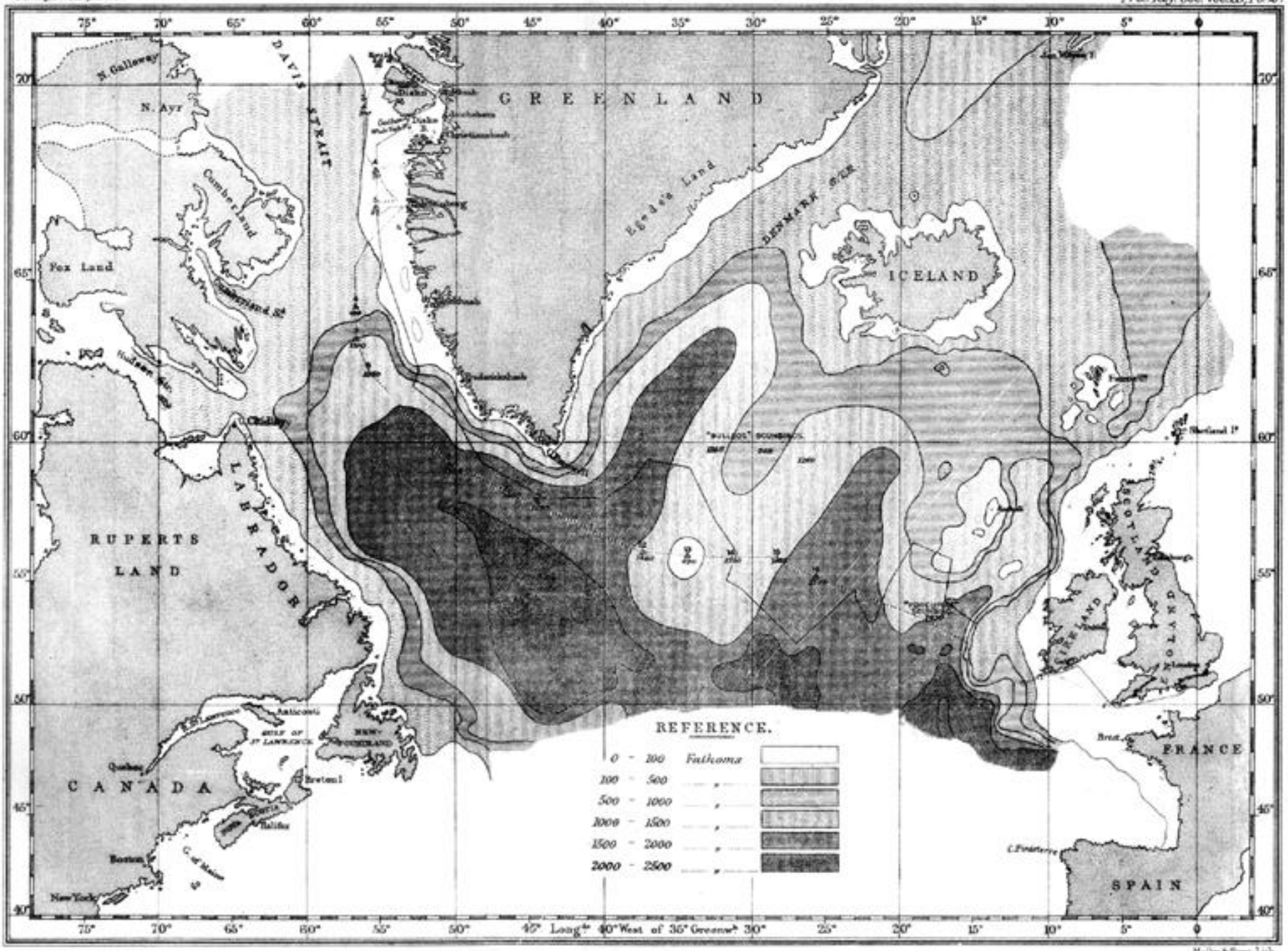
PLATE 3.

Soundings I.–IX. and isotherms between Disco and Davis Strait.

PLATE 4.

Soundings X.–XVII. and isotherms between Davis Strait and England.

* Proceedings of the Royal Society, vol. xxiv. p. 632.



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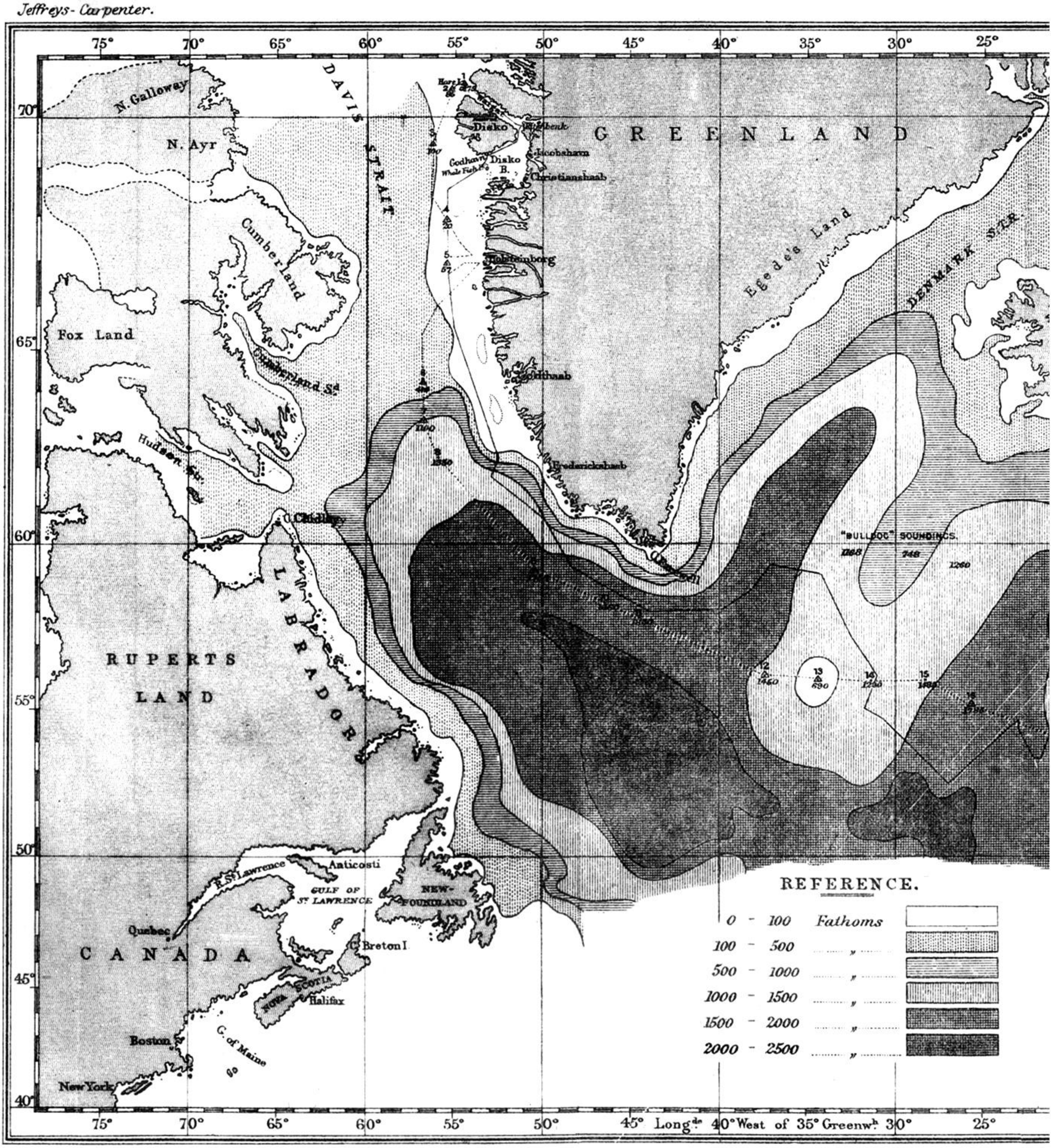

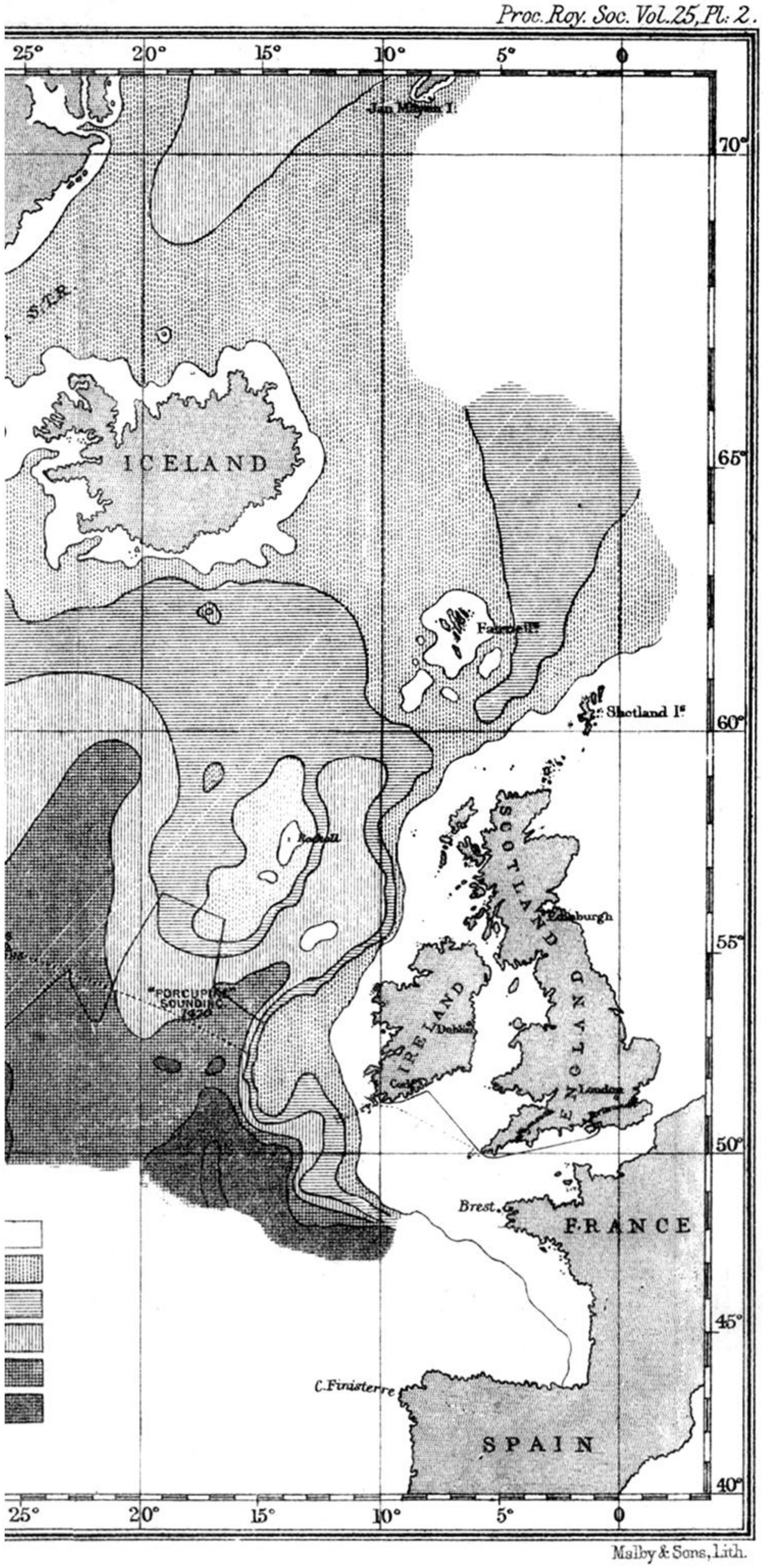

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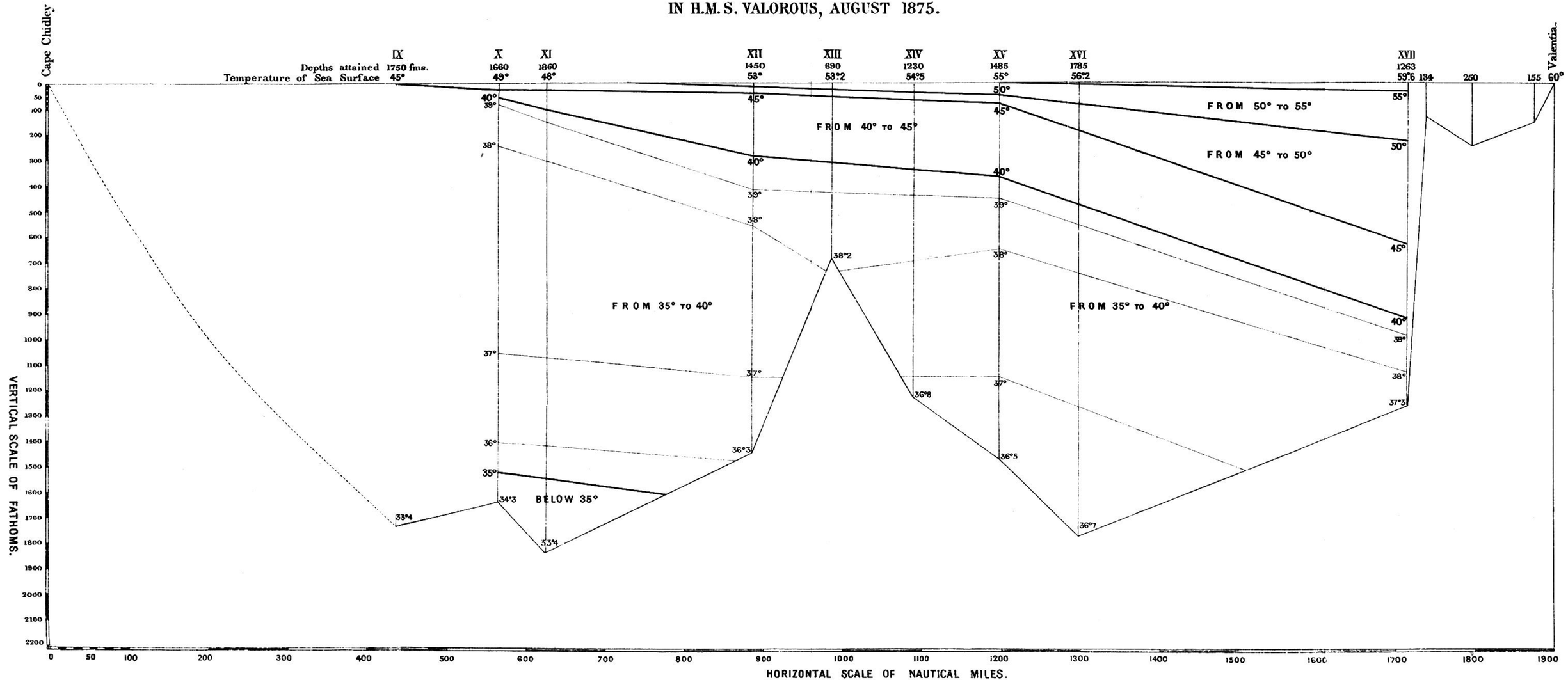

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